The Atmospheric Neutral Density Experiment (ANDE)

A. Nicholas,[1] T. Finne,[1] I. Galysh,[2] M. Davis,[2] and L. Healy[3]
[1]*Space Science Division*
[2]*Space Systems Development Department*
[3]*Spacecraft Engineering Department*

Introduction: The Naval Research Laboratory (NRL) has developed a satellite suite, the Atmospheric Neutral Density Experiment (ANDE),[1] to improve precision orbit determination and prediction by monitoring total atmospheric density between 300 and 400 km. The ANDE Risk Reduction (ANDERR) flight was deployed into orbit by the space shuttle *Discovery* on 21 December 2006 (Fig. 5). The primary ANDERR mission objective, a test of the shuttle deployment mechanism for the follow-on ANDE flight (scheduled for mid-2009), was successful. The primary ANDE mission objectives are to measure the variability of atmospheric density driven by solar and geomagnetic forcings for improved orbit determination and to provide a test object for the U.S. space surveillance network (SSN). A joint effort between NRL's Space Science Division and its Naval Center for Space Technology to routinely process and analyze the ANDE data has led to improved orbit determination and prediction using an atmospheric model correction method. The ANDE data provide a valuable tool for correcting deficiencies in atmospheric models and have led to advancements in miniature sensor technology. These advancements are pivotal for multipoint in situ space weather sensing.

Mission Objectives: The ANDE satellite suite consists of a series of four nearly perfect spherical micro-satellites with instrumentation to perform two interrelated mission objectives. The first objective is to monitor the total neutral density along the orbit for improved orbit determination of resident space objects. The second is to provide a test object for both radar and optical SSN sensors. The DoD Space Test Program will provide launch services for two missions (ANDERR and ANDE), with each mission flying a pair of ANDE spacecraft.

The major source of error in determining the orbit of objects in low Earth orbit (LEO), i.e., altitudes less than 1000 km, is the computation of acceleration due to atmospheric drag. This acceleration is governed by Eq. (1),

$$a_d = -\frac{1}{2} B \rho v^2 , \qquad (1)$$

where a_d is the acceleration, ρ is the atmospheric density, and v is the orbital velocity relative to the medium (including cross-track and radial velocities). Equation (2) defines the ballistic coefficient, B, with C_D being the coefficient of drag, A the projected frontal area, and m the mass of the object:

$$B = \frac{C_D A}{m} \qquad (2)$$

The constant and well-determined cross section and surface properties of the ANDE spherical spacecraft provide an ideal set of objects for monitoring atmospheric drag and for calibrating SSN assets.

ANDE Data Flow: The 20th Space Control Squadron, USAF, in Dahlgren, Virginia, processes the SSN radar observation data of the ANDERR spacecraft. The product is a set of orbital state vectors and corresponding radar observations, which is provided to NRL up to three times a day. These state vectors are processed at NRL using Special-K orbit determination software to produce a set of ephemerides. These ephemeris files are reformatted into the consolidated prediction format used by the International Laser Ranging Service (ILRS) tracking stations. A set of predictions is also computed once per day using the NRL Orbit Covariance Estimation and Analysis (OCEAN) orbit determination code. The radar observation data are merged with the satellite laser ranging (SLR) observation data and processed by OCEAN to generate a 2-day augmented set of predictions that includes the atmospheric correction. Figure 6 depicts the two data flow processes.

Data Processing and Analysis: A comparison between the values of C_D for the two spacecraft from the OCEAN run, using an atmospheric model (NRLMSISE-00) and a priori area and mass information, yields excellent agreement between the two objects even as the altitude separation between the two spacecraft increases due to differential drag. The retrieved values of C_D for the two spacecraft are presented as a function of time in Fig. 7(a). These results are non-physical as the value of C_D is well below the theoretical limit of 2; the atmospheric model is overestimating the density, and the OCEAN code is correcting for this by scaling the B term down to fit the observations. The ANDERR data provide a global climate monitoring metric, which showed a consistent overestimation[2] of total density by climatology models by an average of 26.6%.

The primary drivers of the atmosphere are solar radiation heating and geomagnetic heating. The solar driver is input into the atmospheric model in the form of the $F_{10.7}$ cm radio flux, an easy to measure ground-based proxy for the solar ultraviolet flux that heats the

atmosphere. The A_p index is a measure of geomagnetic activity at the Earth and is used by atmospheric models to drive the geomagnetic heating in the atmosphere. A wavelet analysis was performed on the C_D density corrections: $F_{10.7}$, A_p, and the solar wind velocity (V_{sw}) time series to further investigate the causes of periodicities observed during 2007. The wavelet power spectra are presented in Fig. 7(b–e) as a function of day of year for 2007. The plots have been formatted to a range of 2 to 20 days with white contours representing the 95% significance level. The short-term oscillations (5, 7, 9 days) were much more prevalent and stronger in both the A_p and V_{sw} data in the first half of 2007 than in the second half of the year. This is also evident in the 9-day period in the C_D atmospheric corrections derived from the ANDERR spacecraft orbits. The strong 18-day periods observed in the $F_{10.7}$ data are also observed in the C_D corrections although there is a significant time lag and atmospheric recovery period associated with this data. The analysis technique applied to the ANDERR data set separates geomagnetic forcing of the atmosphere from solar irradiance forcing of the atmosphere.

Sensor Miniaturization: On the second flight of the ANDE program (scheduled for mid-2009), one spacecraft will carry miniaturized sensors to measure the density and composition of the atmosphere. NRL has collaborated with NASA Goddard Space Flight Center to develop a small wind and temperature spectrometer (Fig. 8). The technology push to reduce the size, weight, and power of such sensors is pivotal for multipoint in situ space weather sensing.

[Sponsored by NRL and ONR]

References

[1] A.C. Nicholas, S.E. Thonnard, I. Galysh, P. Kalmanson, B. Bruninga, H. Kelly, S. Ritterhouse, J. Englehardt, K. Doherty, J. McGuire, D. Niemi, H. Heidt, M. Hallada, D. Dayton, L. Ulibarri, R. Hill, M. Gaddis, and B. Cockreham, "An Overview of the ANDE Risk Reduction Flight," Proc. of the AMOS Technical Conference, Maui, HI, Sept. 2002.

[2] A.C. Nicholas, J.M. Picone. J. Emmert, J. DeYoung, L. Healy, L. Wasiczko, M. Davis, and C. Cox, "Preliminary Results from the Atmospheric Neutral Density Experiment Risk Reduction Mission," Proc. of the AAS/AIAA Astrodynamics Specialist Conference, paper #AAS 07-265, Mackinac Island, MI, Aug 20–24, 2007.

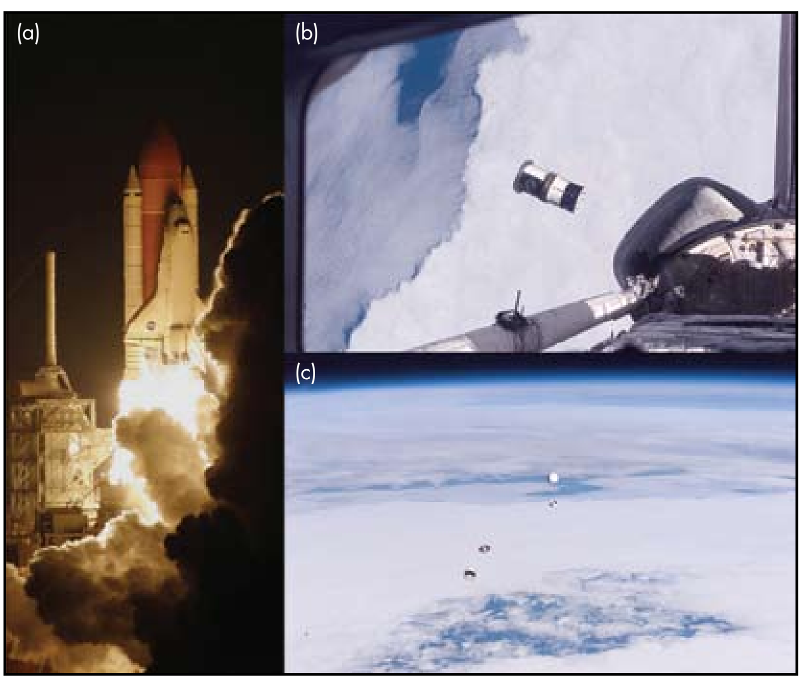

FIGURE 5
The launch (a) and deployment (b,c) of the Atmospheric Neutral Density Experiment Risk Reduction (ANDERR) spacecraft from the space shuttle *Discovery* on 21 December 2006, during the STS-116 mission. (Photos courtesy of NASA)

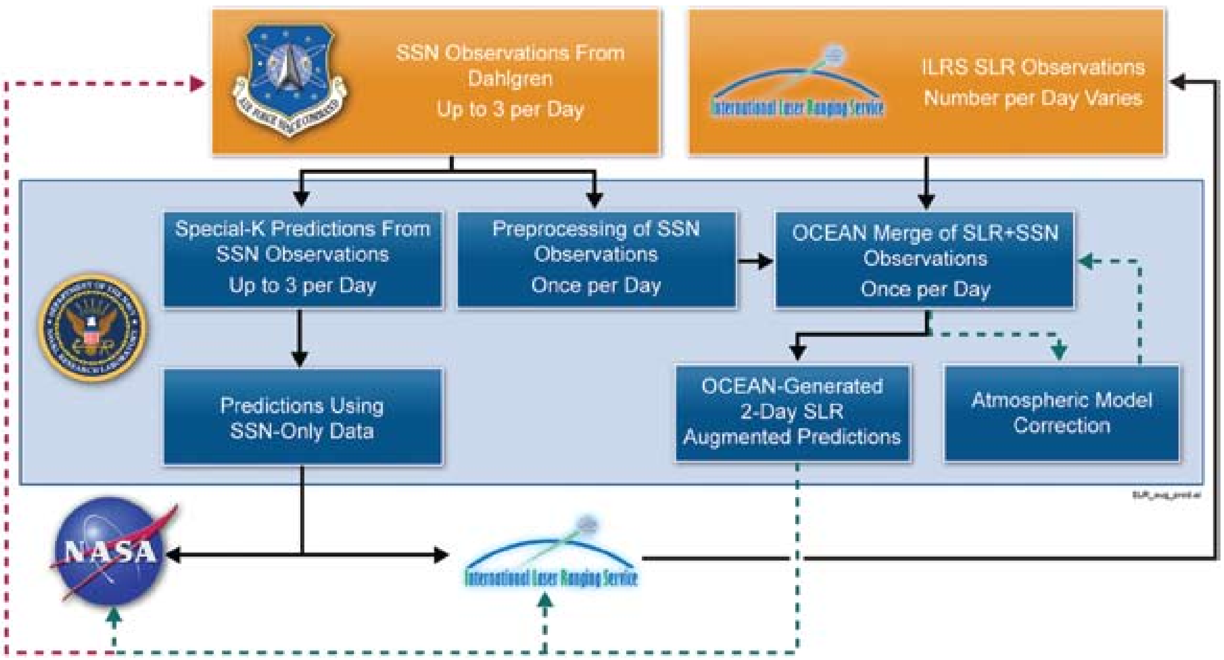

FIGURE 6
The data flow and processing of ANDE observations. The green dashed lines represent functions demonstrated during the ANDERR mission. The red dashed line is expected to be complete after the final ANDE flight.

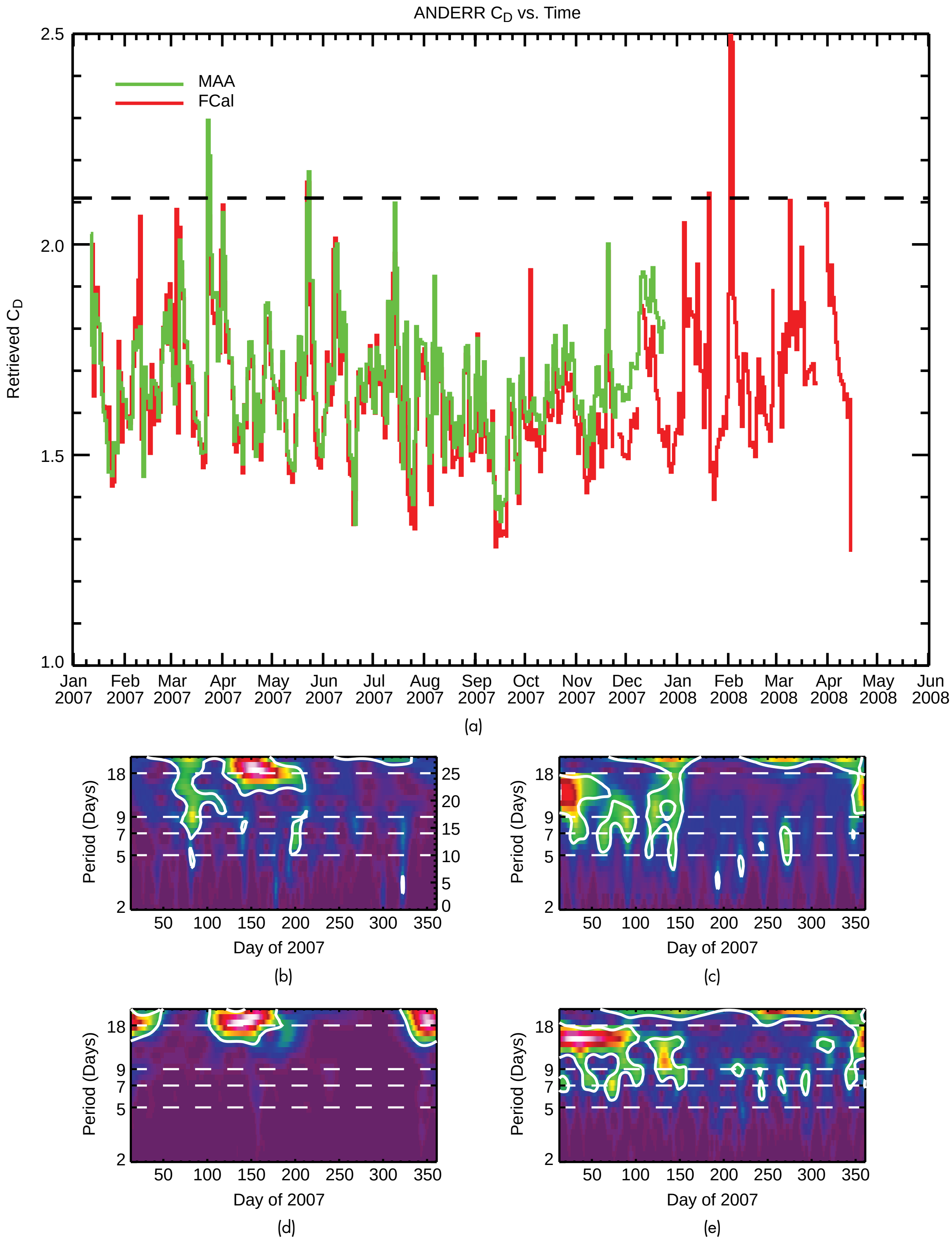

FIGURE 7
(a) OCEAN fitted C_D values, using NRLMSISE-00 for the ANDERR spacecraft. (b, c, d, e) Morlet power spectra for the C_D, A_p, $F_{10.7}$, and V_{sw}, respectively. The white contour is the 95% significance level.

FIGURE 8
The ANDE wind and temperature spectrometer.